Fusion of RTK GNSS receiver and IMU for accurate vehicle tracking

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Outline

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  - IMU-based Sensor Fusion
  - Scenario: unsynchronized GPS and IMU measurements

- Proposed Approach
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  - Simplified approach: bisection search over clock offset with conventional Bayesian smoothing-based tracking

- Experimental Results

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Background – RTK GPS

- Carrier phase tracking
- Centimetre-level accuracy in fixed mode
- Key performance indicator: fixing ratio
- Accuracy significantly reduced in floating mode

Blue dots: RTK fixed  Red dots: RTK float
Background – IMU-based Sensor Fusion

- Sensor Fusion in Wireless Positioning Systems
  - IMU measurements complementary to wireless range measurements

- Advantages
  - Higher Accuracy & Reliability
  - Information on attitude
  - Provide position information during GPS outage (e.g., receiver in tunnels)
Scenario
Lack of clock synchronization between GPS receiver and IMU

\[ t_{IMU} = t_{GPS} - \Delta t \quad (IMU \text{ started late}) \]
Impact of clock offset between GPS receiver and IMU

$\Delta t = 0.5s$

50Km/h

At IMU time 12:00, using the GPS measured at GPS time 12:00, which in fact is the position measured 0.5s ago.
Tracking result without considering the clock offset

GPS

GPS + IMU (EKF)
Tracking result without considering the clock offset

- GPS
- GPS + IMU (EKF)
Proposed approach – Estimate the clock offset in the fusion algorithm

- Problem formulation (Bayesian)

\[ p\left(\{x_k\}_{k=0}^{K}, \Delta t | \{\omega_k, a_k\}_{k=1}^{K}, \{r_n\}_{n=1}^{N}\right) = p_0(x_0)p_0(\Delta t) \prod_{k=1}^{K} p(x_k | x_{k-1}) \prod_{n=1}^{N} p_{\Delta t}(r_n | x_{k_n}) \]

- Extremely hard to solve (linearization in EKF, Monto Carlo method in PF)
- Reason: \( \Delta t \) controls \( k_n \), the association between GPS and IMU measurements.
The role of $\Delta t$

When $\Delta t = 0$,

$\Delta t = 0$

......

GPS clock

IMU clock

When $\Delta t > 0$,

$\Delta t > 0$

......

GPS clock

IMU clock
Proposed approach

- For a given $\Delta t$
  - Work out the association between GPS and IMU measurements
  - Apply conventional sensor fusion algorithm (Bayesian smooth)

$$\Delta t: \{\omega_k, a_k\}_{k=1}^{K}, \{r_n\}_{n=1}^{N} \Rightarrow \{x_k\}_{k=0}^{K}$$

- If $\Delta t$ is correct, the estimated trajectory $\{x_k\}_{k=0}^{K}$ should be consistent with the GPS measurements $\{r_n\}_{n=1}^{N}$

- Search over $\Delta t$, find the clock offset that results in the highest consistency between the estimated trajectory and the GPS measurements (minimum RMSE)

- Since the dimension of $\Delta t$ is one, the search can be done efficiently using bisection method
Experiments

- GPS and IMU are independently packed modules – no means to drive both devices with one clock
- “Manual synchronization” attempted (press the start buttons for both devices at the same time)
Experiments

Relationship between the RMSE and clock offset

“Manually Synchronized” to 0.4 s!
Results – Example 1 - No clock offset correction

GPS

GPS + IMU (EKF)
Results – Example 1 – With clock offset correction

GPS

GPS + IMU (EKF)
Results – Example 2 - No clock offset correction
Results – Example 2 – With clock offset correction

GPS

GPS + IMU (EKF)
Conclusion

- Clock synchronization between GPS and IMU critical for vehicle tracking
- Arrives when developing sensor fusion systems with independently-packed GPS receivers and IMUs
- Include clock offset as a nuisance parameter to be estimated along with the trajectory
- Simplified to bisection search with conventional Bayesian smoothing-based tracking
- With the clock offset worked out, the data can be corrected and used for scientific research or engineering test